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ABSTRACT

Experimental investigation of the applicability of CdO films as transparent ohmic contacts with CdS (single-crystal and film type) photoconductors. The determined optical and electrical properties of both CdO films and CdO-CdS contacts indicate that this type of contact should be well suited for use in photoelectric devices, particularly in the case of longitudinal photoconductivity. The CdO films investigated exhibit low resistivity and temperature dependence over a wide temperature range, combined with a high transmission coefficient and a linear current-voltage characteristic.

Introduction

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Cadmium sulfide type photoconductors (CdS, CdSe, CdTe) became widely used in the production of photoelectric devices (photoresistors, photocells, photocapacitors, photopotentiometers, phototriodes, photoamplifiers). At the same time the problem of producing contacts for these semiconductors still cannot

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*Numbers given in margin indicate pagination in original foreign text.

be considered completely solved. Contacts affect significantly the characteristics and the parameters of photodiodes, especially their current-voltage, transitional and frequency characteristics, their noise level and sensitivity threshold as well as sensitivity, stability and service life.

For the majority of practical applications it is necessary to produce an ohmic contact between the photoconductor and the metal electrodes which is characterized by a linear current-voltage characteristic and low noise level. This insures a sufficiently low threshold sensitivity.

For many photodevices this contact must be not only ohmic, but also transparent in the region of spectral photosensitivity of the semiconductor. Naturally transparent contacts of CdS and its analogs are obtained by means of In_2O_3, SnO_2 or thin semitransparent indium and gold film. At the same time, from the above list, only the indium contact is ohmic. The technology of production of semitransparent indium contacts is extremely complex (ref. 1) and it finds very little application. Thus, the development of technology and the investigation of the properties of transparent ohmic contacts for cadmium sulfide types of compounds is still a real problem.

It is well known (ref. 2) that bombardment of the CdS surface with ions produces linear contact, the properties of which are little dependent on the metal which was used. This stems from the fact that during bombardment of cadmium sulfide with ions, a certain fraction of CdS molecules dissociates, producing a thin cadmium-enriched layer or even a thin film of metallic cadmium, which in fact produces the ohmic contact with the semiconductor. Especially favorable properties were displayed by the cadmium contact produced by cathode sputtering (ref. 3) since the cadmium oxide film, produced by a reactive cathode sputtering of cadmium in air or oxygen atmosphere, has high n-type

conductivity, which is determined by the excess Cd. This should favor /41
the production of ohmic contact with a single crystal or semiconductor film, since the semiconductor in the beginning of the sputtering process is processed by ionic bombardment.

Depending on the sputtering conditions one may obtain cadmium oxide film which is transparent almost over the whole range of the visible spectrum, i.e. in the regions of spectral sensitivity of cadmium sulfide, selenide and telluride.

In view of these considerations, we investigated the properties of contacts of single crystals and films of cadmium sulfide with CdO films produced by cathode sputtering and also the optical and electrical properties of cadmium oxide films as material for transparent ohmic contacts for CdS-type semiconductors.

1. Technology of Production of Cadmium Oxide Films

Cadmium oxide films were obtained by cathode sputtering of metallic cadmium in a low vacuum. The cathode was producing cadmium in the shape of a disk. The backing is placed on the water-cooled iron anode. From reference 4 it is known that to obtain a uniform thickness film, the ratio of the cathode-anode distance to the diameter of the cathode must be as small as possible. On the other hand the cathode-anode distance cannot be any less than a certain value, since for the intense deposition of film it is necessary for the backing to be placed at the boundary of the dark space and the negative glow discharge. The optimum cathode-anode distance and other parameters, selected experimentally, were as follows: diameter of the cathode--6 cm, cathode-anode distance--1.6-1.8 cm, current--50-70 ma, potential--600 v, air pressure--0.4-0.65 mm. During the deposition of cadmium oxide on the glass backing, the glass must first be covered and after the establishment of stationary discharge, which corresponds to the working current, the cover is removed. In obtaining transparent cadmium oxide contacts for single crystals and cadmium sulfide films, sputtering was conducted beginning with 10 ma current, after which it was gradually increased. This enabled us to avoid the production of an opaque Cd layer on the surface of cadmium sulfide. When the above parameters are met the rate of deposition of cadmium oxide film comprises 500-600 Å/min (fig. 1).

2. Electrical and Optical Properties of Cadmium Oxide Film

All of the obtained cadmium oxide films had n-type conductivity. Their resistivity, measured by the 4 probe method (ref. 5), was independent of temperature in the -100 - +70°C range and comprised $(3.2\text{-}6.4)\cdot 10^{-3}$ ohm·cm. These data do not contradict literature values (refs. 6,7), although the fact that resistivity is independent of temperature in the broad temperature interval is not a trivial fact and will require more detailed investigation in order to be explained. Two possible causes can be cited for this effect: formation of an impurity zone and formation of bridges with free excess cadmium.

A direct measurement of the resistance of the film gave results which are in agreement with the calculated values from the resistivity. The /42 measurement of the potential distribution along the length of the cadmium oxide film did not reveal any nonuniformity of values.

Figure 1. Thickness of CdO film as a function of deposition time.

1 - cathode-anode distance is 1.8 cm; 2 - 1.6 cm.

Figure 2 shows the spectral dependence of the transmission coefficient of cadmium oxide films. The dotted line indicates the spectral dependence of cadmium sulfide photoconductivity. It can be seen that when the film thickness $d \leqslant 4000$ Å, its transmission coefficient in the maximum photoconductivity region for cadmium sulfide $k \geq 0.5$. In the maximum photosensitivity region of cadmium selenide and telluride, it increases to 0.7-0.8.

3. Properties of Cadmium Oxide Contact for Cadmium Sulfide Single Crystals and Film

The properties of CdS-CdO contact were investigated by the measurements of current voltage characteristics and noise characteristics and also by the study of the potential distribution in the contact regions. During the study of current voltage characteristics, indium-gallium eutectic served as the second contact,

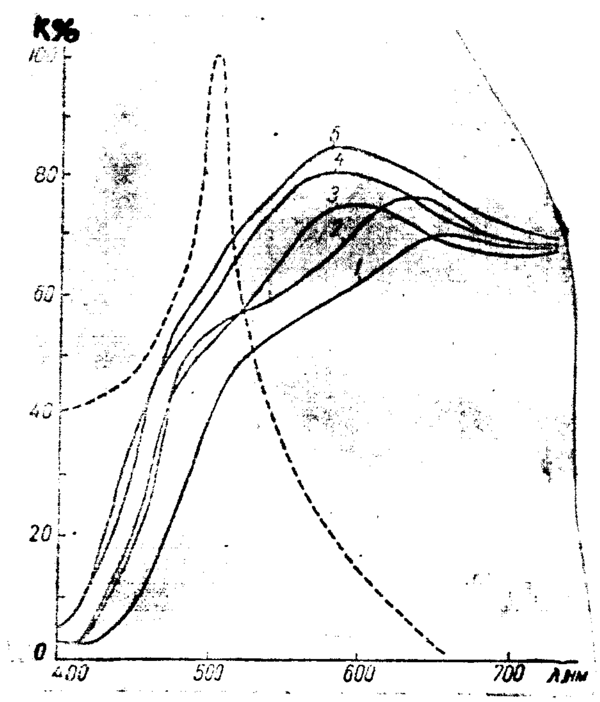

Figure 2. Spectral dependence of the transmission coefficient of CdO films. 1 - film thickness 4800 Å; 2 - 3910 Å; 3 - 3250 Å; 4 - 2550 Å; 5 - 2200 Å.

which produces with cadmium sulfide an ohmic antisaturation contact. Figure 3 shows current-voltage characteristics of films of cadmium sulfide with cadmium oxide contacts taken at different temperatures with different illumination. The characteristics which correspond to the reverse polarity are completely symmetrical to those which are shown here.

The investigation of the distribution of the potential along the cadmium sulfide film with cadmium oxide contacts showed that near the gradient /43 the potential distribution decreases as compared with sections far removed from the contact, which may indicate the formation of an antisaturation layer (fig. 4). The table shows the results of measurement of the low frequency noise in

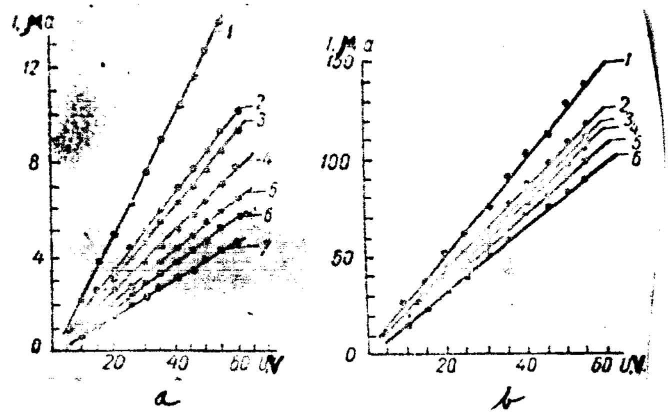

Figure 3. Current-voltage characteristics of CdS film with cadmium oxide contacts.

a: in the dark at different temperatures (the dark resistance of the film at room temperature $R_T = 6\cdot10^4$ ohms), 1 - temperature T = 82°C, 2 - T = 32°C, 3 - T = 13°C, 4 - T = 6°C, 5 - T = -24°C, 6 - T = -110°C, 7 - T = -156°C; b: at different illuminations at room temperature ($R_T = 3\cdot10^9$ ohm), 1 - illumination L = 1800 lux; 2 - L = 864 lux, 3 - L = 666 lux, 4 - L = 576 lux, 5 - L = 360 lux, 6 - L = 234 lux.

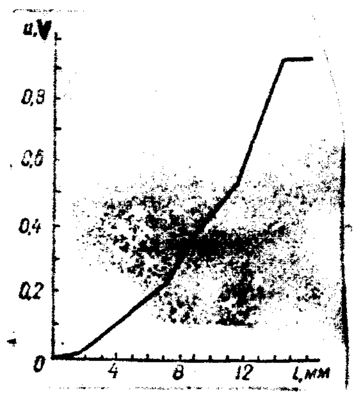

Figure 4. Potential distribution along the CdS film with cadmium oxide content.

TABLE

Type of contact	CdO		Cd	
Level of steady illumination, lux	Noise level, μV	Sensitivity threshold, nanolumen	Noise level, μV	Sensitivity threshold, nanolumen
0	0.7	33.2	0.5	7
10	40	33.2	16	44
102	120	60	36	80

the Δf = 270 Hz band for CdS crystals with CdO and Cd contacts. The low noise level indicates ohmic CdS-CdO contact. At the same time the cadmium oxide contact is poorer than the cadmium contact at high illumination levels.

Conclusions

The results of the investigation of the current-voltage characteristics and the noise characteristics of the CdS-CdO contact show that it is a stable, transparent, ohmic contact. It is the opinion of the authors that the linearity of the contact results from the formation of a thin, cadmium-rich film on the surface of CdS. CdO films obtained by the reactive cathode sputtering are also enriched in cadmium and the excess cadmium insures a high conductivity. The possibility is not excluded that at the CdS-CdO boundary a thin transparent Cd film is produced which aids the formation of antisaturation contact.

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